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DEPARTMENT OF THE ARMY PROJECT No. 5B03-03-001
ORDNANCE RESEARCH AND DEVELOPMENT PROJECT No. TB3-0108

BALLISTIC RESEARCH LABORATORIES

ABERDEEN PROVING GROUND, MARYLAND

B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

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A B E R D E E N   P R O V I N G   G R O U N D,   M A R Y L A N D

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MRLewis/DBSleator/arc
Aberdeen Proving Ground, Md.
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ABSTRACT

The development of a short duration light source (three microseconds to half peak) of high intensity from an exploding wire is described. Experimental proceedures are given. Tables and oscilloscope traces of intensity versus time as a function of various wire parameters are presented.

The duration is shorter than that usually obtained with an exploding wire. The use of yarns made of extremely fine wire such as steel wool or flash bulb filler seems to account for the short duration.

The light is of such an intensity that a bandwidth of 16A° in the 4358A° region yields interferograms of greater density and contrast than those obtained with the BH-6 tube source previously used.

INTRODUCTION

We report here the development of a light source for use with the ten inch Mach-Zehnder interferometer on the Pressure-Temperature Controlled Range of the Air Flow Branch, Ballistic Research Laboratories. Such a light source must have a higher intensity and a duration not much longer than the previous source used. It was decided that the exploding wire[1/*] might be the desired source.

The light source previously used in the ten inch interferometer and presently being used in a two inch interferometer is a BH-6 mercury quartz tube[2/] which is about two inches long and which gives a line of light about one inch long and 3/32 inches wide. With this source the duration obtained is three microseconds to 1/e of the peak. The quality of the light is that of the mercury spectrum, consisting mostly of lines and little continuum. The 4358A° line is used most often for taking interferograms. This line or any other line is isolated by passing the light through a carbon disulphide prism monochromator.

The desired characteristics of a light source for use in high speed interferometry are as follows:[3,4,5,6/]

1. Extremely high intensity such that after passing through a monochromator the light is still very intense.
2. Short duration (order of magnitude of five microseconds).
3. Practicality
4. Reproducibility
5. Economy
6. Safety

The objective, then, is to find out if the exploding wire satisfies the above conditions.

Briefly the principle of the exploding wire is as follows: When a large amount of electrical energy is made to dissipate quickly through a fine wire the wire "explodes", that is it vaporizes rapidly and gives

* References to Bibliography, Appendix VII

off light and heat and produces a sharp loud sound - thus the term, "exploding". The exact details of the process will not be gone into here, but it may be said that the factors which determine the characteristics of the exploding wire, i.e., intensity, duration, temperature, spectral quality, etc., are: The amount of energy applied; resistance, inductance, and capacitance of the circuit and wire; and length, diameter, and material of the wire. No attempt will be made in this report to describe exactly why the characteristics of the radiation from the wire vary with a change in the circuit and wire parameters. Reference is made to Appendix I on construction and operation of exploding wire device.

RESULTS

Reference is now made to the appendices for details of experiments performed and detailed results. The results below refer to the exploding wire as finally installed on the interferometer.

The exploding wire device as finally installed in the monochromator input to the ten inch interferometer is pictured in figures 1 and 2. Light from the wire passes through the entrance slit in the top of the black bakelite box (Fig. 1), is collimated by the lens below the prism, dispersed by the prism, and focused by the lens above the prism onto the exit slit at the top of the picture. Figure 2 is a photograph of the details of the exploding device inside the bakelite box with two sides open. This set-up differs from the experimental set-up mentioned in Appendix I only in that it is much smaller and more compact. The wire used is a piece of yarn spun from several filaments of ordinary flash bulb filler.* It is an inch long and mounted on a square piece of cardboard which is inserted in jaws mounted under the slit at the top of the bakelite box. The energy input to the wire is 780 joules, i.e., 2.5 μfd charged to 25KV. The fraction of this energy which goes into visible light is not known. The wavelength used (4358A°) is sighted in by shining a mercury lab-arc through the monochromator from the exit slit toward the entrance slit. Any wavelength can be selected at will because the intensity of the continuum from the wire is almost as strong as that from

* Aluminum or aluminum alloy available in number 2 or 22 Photoflash bulbs.

the lines. Duration of the light depends upon the wavelength used (as may be seen in time resolved spectrograms in Fig. 13, Appendix VI) and in general is of the order of three microseconds to 1/2 of the peak intensity.

A smaller slit width must be used with the exploding wire than with the BH-6 tube because of the spectral quality of the light. The 4358A° line from the BH-6 tube is narrow and there is little continuum whereas the spectrum of the wire is mainly continuum. With a slit width of 0.70"- that used with the BH-6 tube - the wire gives films of exceedingly high density, but with too few fringes. To obtain more fringes it is necessary to cut the slit width down to .020" yielding a bandwidth of 16A° with a decrease in density. Despite this narrowing of the slit there is still an appreciable increase in density and contrast over interferograms taken with the BH-6 tube. Figures 3 and 4 are graphs comparing the density and contrast obtained with the wire to that obtained with the BH-6 tube. For various reasons the field with either source is not too uniform. Figure 5 is a positive print of a interferogram taken with the BH-6 tube and figure 6 is one taken with the exploding wire. Figure 5 received one fourth the exposure of figure 6 in printing. Half the exposure of figure 6 would have rendered it completely black. Figure 7 shows traces of monochromatic intensity versus time for the BH-6 tube and the exploding wire. The 4358A° region of the wire is just as intense and a little shorter than the 4990A° region and was used for taking interferograms because the prism has greater dispersion in this region.

CONCLUSION

The exploding wire seems to be a suitable light source for use in the ten inch Mach-Zehnder Interferometer. It has a short enough duration and it seems that its peak light intensity is several times greater per unit area of source size per unit time than that of the BH-6 tube. A yarn made of extremely fine wire seems to give a shorter duration than a single strand wire of the same diameter as the yarn and under the same conditions.

The arrangement presently being used is probably not the optimum attainable. Various modifications such as increased circuit inductance and exploding two wires side by side are to be tried. Increasing the inductance of the circuit may also increase the duration. It may be that we are already at the optimum conditions, for a duration of not too much more than five microseconds cannot be tolerated. Exploding two wires side by side may create a Mach-stem of which the intensity may be a great deal higher and the duration much shorter.

Further conclusions on the results of preliminary experiments performed are included in the appendices.

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APPENDIX I

EQUIPMENT AND METHOD OF EXPLODING WIRE

Construction

The experimental unit was constructed on a portable table. The wire and sphere gaps were housed in a Bakelite box with a slit opposite the wire on the front and a hinged back to cut out stray light. Heavy metal blocks, studs and wire braid with large cross sections were used as conductors to minimize inductance and r.f. radiation. The circuit diagram is shown in Fig. 8.

Safety Devices

A spring-loaded pivoted arm was installed in the bakelite box. This arm is actuated by the opening or closing of the back of the box. When the box is closed the arm pivots away from the high voltage sphere terminal. When the lid is opened the spring snaps the arm, which is grounded, into contact with the sphere terminal and discharges any voltage remaining on the capacitors C_1. Also SW-1, which is used to initiate the firing pulse, is actually a two section switch, one side of which is normally open and the other side normally closed. The normally closed side is connected in series with the 110 VAC line to the BETA high voltage supply. When the switch is pushed it simultaneously fires the wire and interrupts the AC going to the power supply. This causes the relay in the high voltage supply to open and break the high voltage feed.

Theory of Operation

Initially C_1 is charged to 25 K.V. The voltage dividers R_2 and R_3 cause 25 K.V. to appear on S_1 and 12.5 K.V. to appear on P, a metal plate. S_2 is grounded through the wire. The gaps S_1 P and PS_2 are set so that they will break down at about 15 K.V.; therefore they hold off the 12.5 K.V. potential. When SW-1 is closed the 2050 thyratron forms a pulse which is fed to the 5022 thyratron. The 5C22 momentarily grounds P causing 25 K.V. to appear across S_1 P. In the process of the arc which then appears between S_1 and P there is a drop of 25 K.V. across PS_2. PS_2

arcs and a full connection of the wire across C_1 is accomplished. The total amount of energy input to the wire is given by the formula $E = (KV)^2 \frac{C}{2} = 781$ joules in this experiment.

APPENDIX II

Measurements on White Light Intensity As a Function of Time

The light from the wire was focused by an f 1.2 lens, masked down to about f 24 to avoid saturation, onto an RCA 929 photocell connected to a Tektronix five inch oscilloscope across a 1000 ohm resistor. A 35mm camera was used to photograph traces of intensity versus time. (See Fig. 9)

Results and Remarks

In Fig. 10 are listed the results of exploding different types of materials under several modifications. A few traces are reproduced in Fig. 11. The traces have shown that there is a peak of 2.5 to 10 microseconds to half intensity followed by a long tail. This tail extends for almost 100 microseconds for most wires used. It may be seen that glass capillary tubing can cut this tail off, but with a corresponding increase in peak duration up to about 25 microseconds to half intensity and with a decrease in intensity of a factor of 1/3 to 1/2.

It also seems that a 5 cm. wire is more efficient with regard to light per unit length than a 10 cm. wire. This is to be expected since the same amount of energy is being dumped through the 5 cm. wire as through the 10 cm. one. For a decrease in length of 1/2 the corresponding decrease in intensity is only 1/10 to 1/5. It will be shown later in the report that the tail is due to the metal lines in the spectrum of the wire.

The absolute intensity values given in Figure 10 represent an estimate based on the geometry of the experimental set-up and the characteristics of the 929 tube. Assumptions made were: 1) that the photocell was far enough away from the wire so that the light front was spherical, 2) that the response of the photocell was linear even though it was being overloaded a factor of 500 times its current capacity according to the tube manual, and 3) that the particular photocell being used did not differ in its characteristics from those given in the tube manual for it. The second assumption was based on linearity tests made with sheets of Polaroid. The peak heights (see Fig. 11) on the film

were measured in Telereader counts on a Telereader. The appropriate conversion factors and the geometry of the system gave a final result of 12,100 candlepower per Telereader count. The absolute peak intensities in millions of candlepower are listed in Fig. 10. These results on absolute intensity fall below by a factor of about 50 those of Heine-Geldern.[7/] It may be noted that his circuit used less energy than the one herein described.

Of further note is the mechanism by which the glass tubes act as a shutter. In every case the tube shattered. There are a number of explanations for the shutter effect, the two easiest being that either the glass was coated on the inside by an opaque metal film or the shattered glass scattered the light by internal reflections and refractions. Other explanations involve the exact light producing mechanism which needs to be investigated further before any definite statements are made.

The steel wool yarn seems to give the best results from the standpoint of intensity and duration. This yarn is made by twisting several strands of steel wool together. Other experiments have shown that an aluminum yarn made from flash bulb filler yields results comparable to steel wool yarn and is easier to handle.

APPENDIX III

TIME RESOLVED SPECTRA

Method

As in Fig. 12 the light from the wire was focused on a pinhole by a condensing lens and collimated and reflected into the prism so that the direction of dispersion was vertical. Another lens was then placed so that the spectrum was reflected by the rotating mirror and came to a focus on the film plane. The rotating mirror axis is vertical so that the direction of time resolution is horizontal. Time resolved spectra are shown in Figs. 13, a., b., and c.

Results and Remarks

The aluminum yarn used was made from flash bulb filler. It may be noticed that the aluminum, steel wool, and magnesium spectra have some common lines. This indicates that these lines may be due to air gases. The thickness of these lines indicates that they may actually be groups of lines. Furthermore it may be noticed that there is also a strong continuum and that the continuum also has a short duration. The metallic lines seem to have a much longer duration than the lines tentatively identified as air lines.

APPENDIX IV

EXPLOSION DIAMETER AS A FUNCTION OF TIME

Method

As in Fig. 14 the wire light was focused onto a vertical slit. The image was then focused so that it was reflected by the rotating mirror and came to a focus on the film plane. The diameter of the luminous region determines the height of the image on the film while the time resolution is in the horizontal direction.

Results and Remarks

The luminous region of the exploding wire is a rapidly expanding cylinder. Initially the velocity of expansion is extremely high and diminishes as the diameter becomes larger. The velocity of the luminous front in the first one-eight of a microsecond as measured from Fig. 15 (a) on the Telereader is 21,800 feet per second - roughly Mach 20. Fig. 15 (b) shows how the capillary tube acts to cut off the light after the luminous front has travelled the radius of the tube.

APPENDIX V

Comparison of Exploding Wire to BH-6 Tube Source

From the time resolved spectra of aluminum and steel wool yarns it was decided to use for our monchromatic light in this experiment the line or closely spaced group of lines that appears in the 4990A° region. The intensity and duration of these lines were compared to the intensity and duration of the 4358A° line of the BH-6 tube.

Method

As in Fig. 16 the light from the source fell upon the slit and was collimated by a lens. Since the wire and slit were horizontal and it was desired that the spectral lines be vertical, a system of mirrors was installed to rotate the collimated beam 90° before it went into the CS_2 prism. A lens focuses the dispersed rays so that they may be separated and detected by the photocell. Two traces are reproduced in Fig. 7.

The 4990A° region was sighted in using an air spark. The results were corrected for wavelength response of the phototube and difference in source sizes (the size of the wire source at peak is .43 inches and the BH-6 tube is 3/32 inches).

Results and Remarks

It is difficult to correlate the two sources because of their difference in quality i.e., the wire presents a continuous spectrum while the BH-6 tube presents a spectrum of little continuum. This difference makes it difficult to determine the actual bandwidths or their ratio. Keeping this in mind we find that for the same size slit width the peak light from the wire in the 4990A° region is 5.5 times as great as the peak light from the BH-6 tube in the 4358A° region. A possible error that would make the factor larger, but not smaller, is that the wire may not have been centered exactly in and parallel to the slit.

Figure 17 shows the stopping power of the exploding wire light. The image of the fringes and the two pieces of tape was swept across the film at 975 meters per second. It may be seen from the picture that measurements to one millimeter are possible.

REMARKS ON APPENDICES I THROUGH V

The results of the time resolved spectra and explosion diameter versus time experiments may be coupled together to give some rather interesting information which is not within the scope of this report. Information may be obtained from these experiments regarding the continuum intensity as a function of time and temperature with a relation to the degree of ionization in the luminous region; properties of the shock front ahead of the luminous region including temperature, velocity, relation to continuum intensity, and pressure. Obtaining this information would require the application of the flow equations for cylindrical shock waves produced by instantaneous energy release.[8]

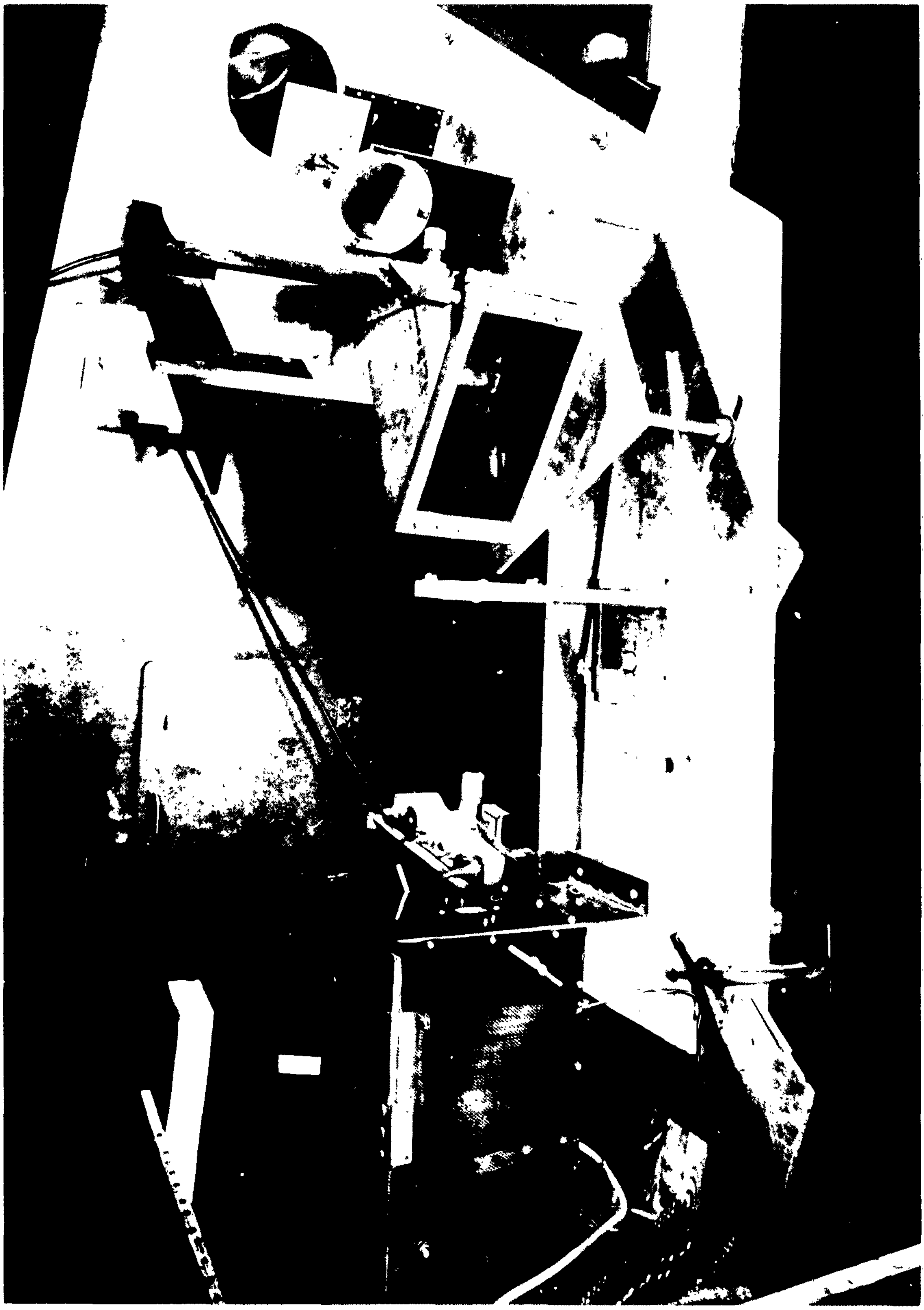


Figure 1. Monochromator.

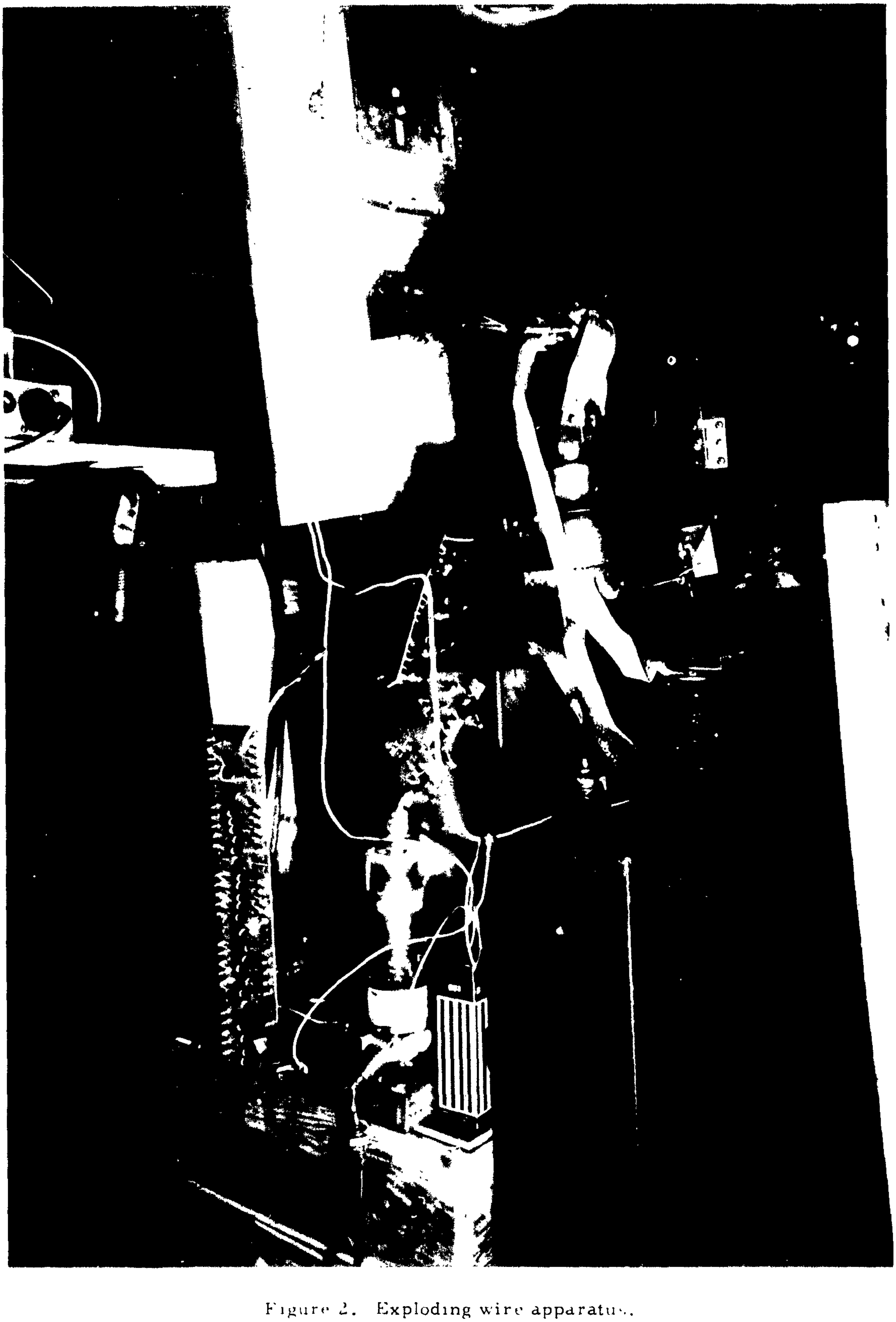
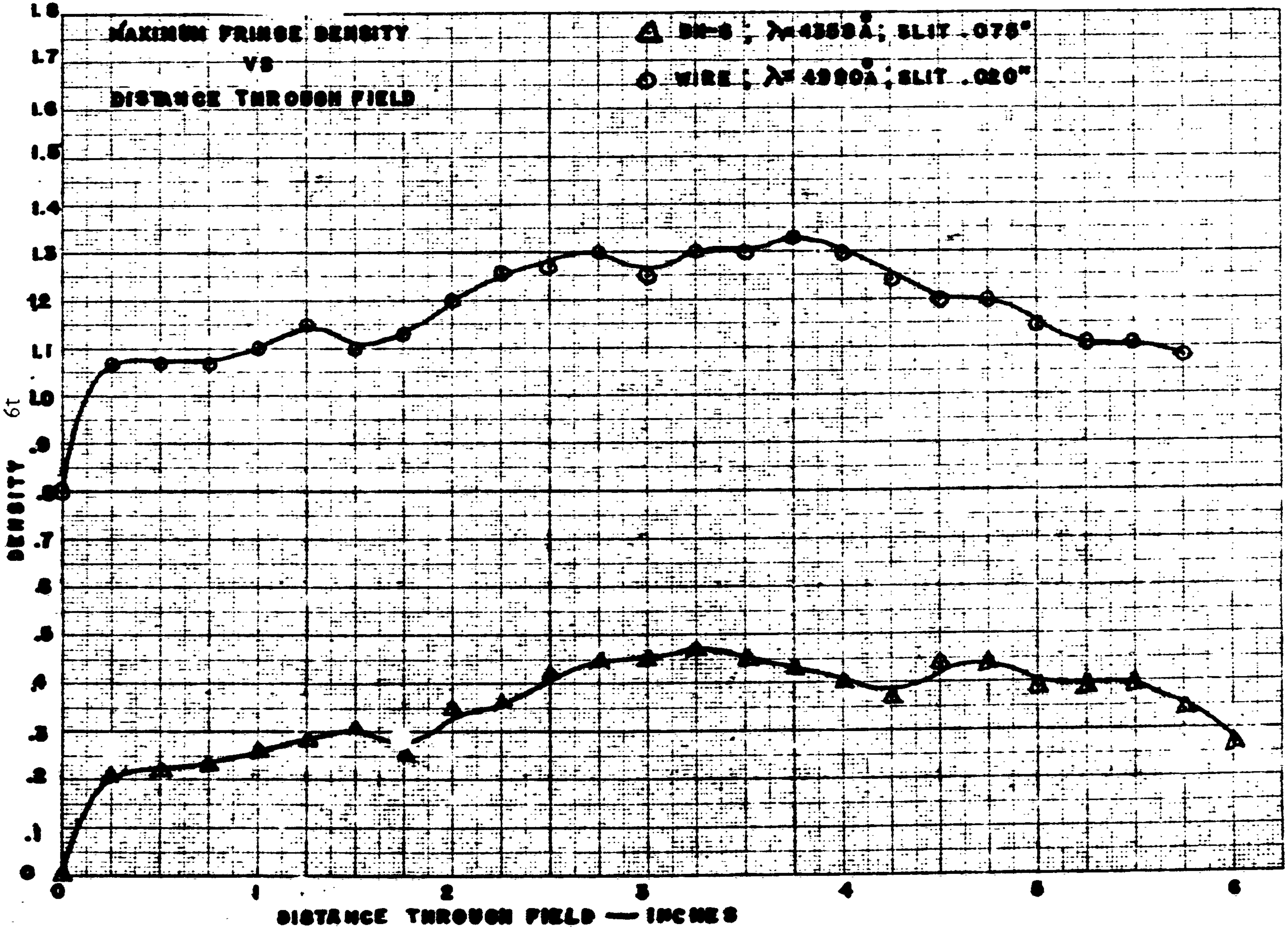


Figure 2. Exploding wire apparatus.

Figure 3.



MAXIMUM FRINGE DENSITY
VS
DISTANCE THROUGH FIELD
DENSITY
DISTANCE THROUGH FIELD — INCHES

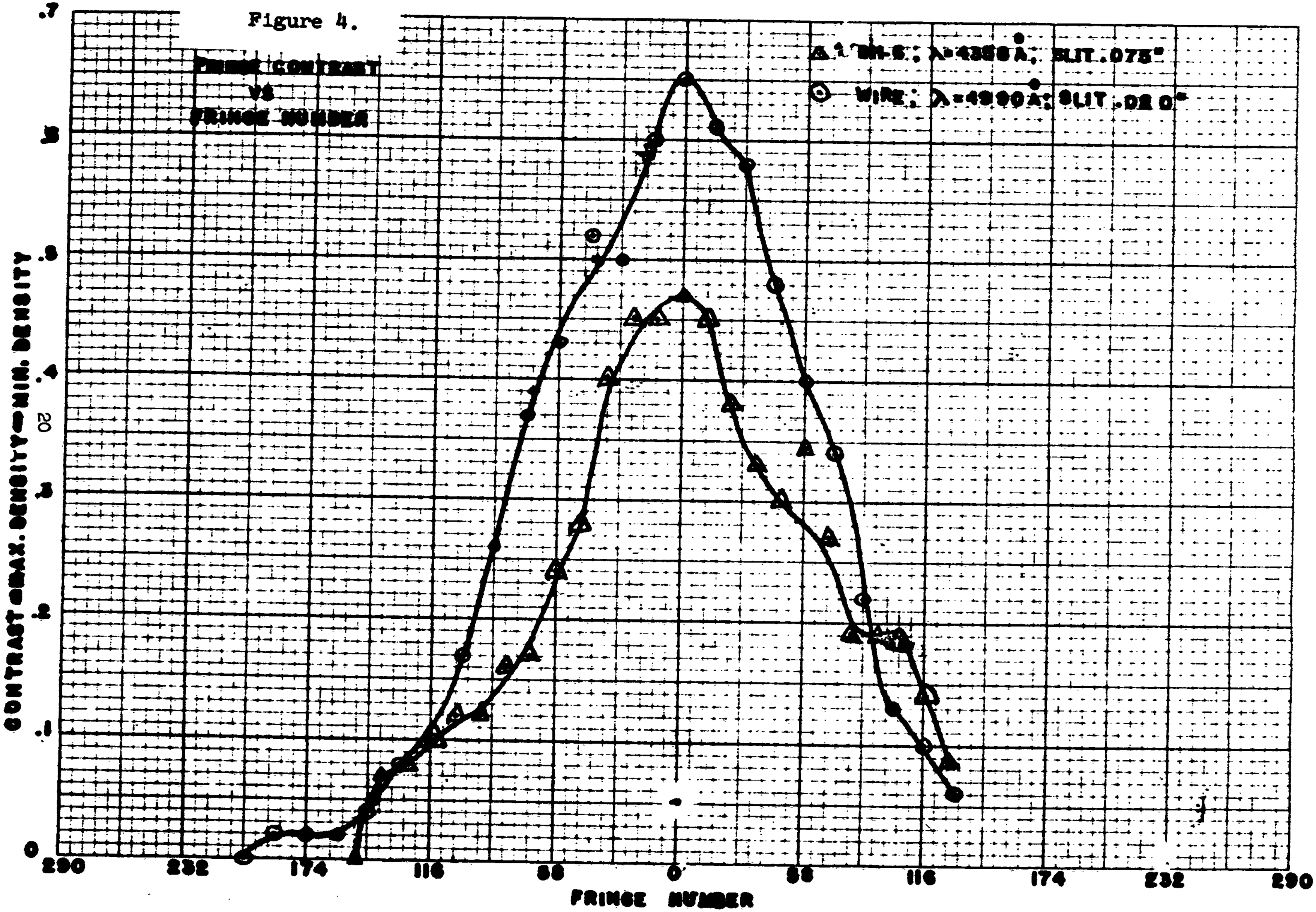

FRINGE CONTRAST
VS
FRINGE NUMBER
WIRE; λ=4990Å; SLIT .020"
CONTRAST=MAX. DENSITY−MIN. DENSITY
FRINGE NUMBER
0
.1
.2
.3
.4
.6
.7
290
232
174
116
58
0
58
116
174
232
290

Figure 4.

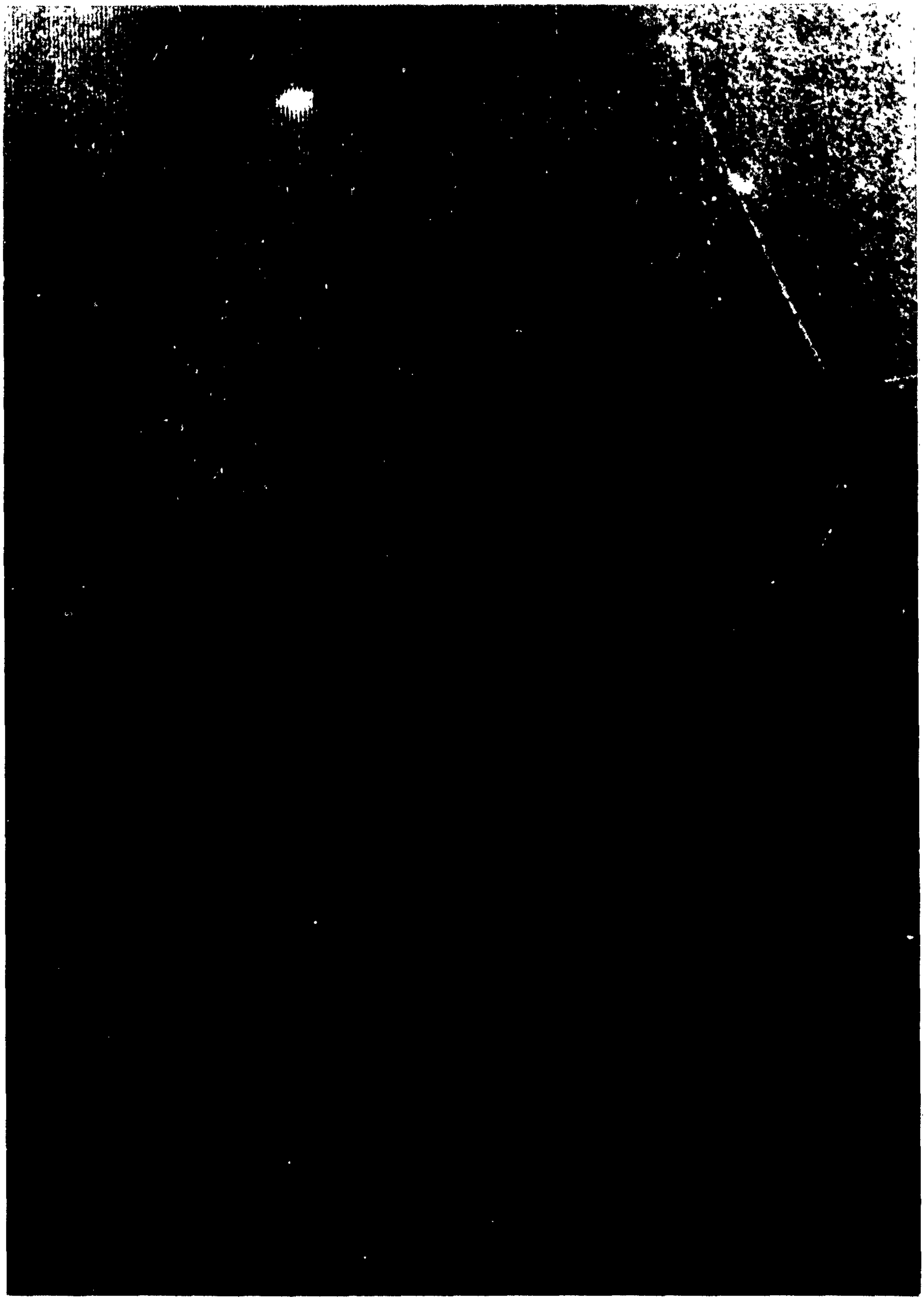


Figure 5. Interferogram-BH-6 Tube.

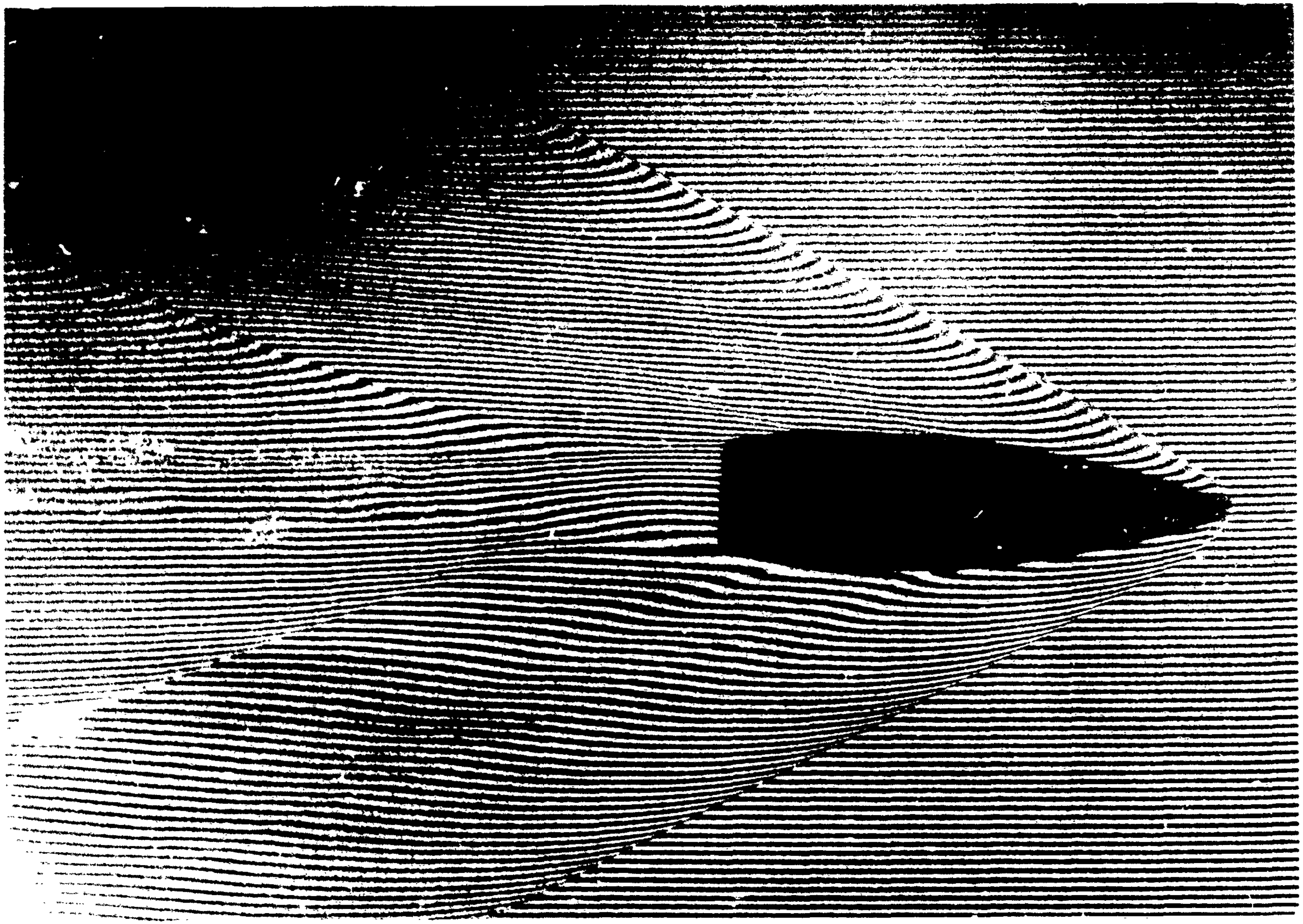


Figure 6. Interferogram-Exploding wire.

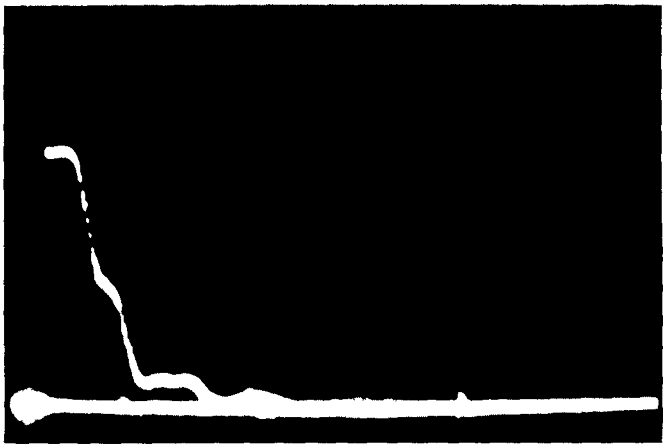


Figure 7a. Intensity (arb. units) vs. time (1/2" equals five microseconds). Exploding wire, 4990A°.

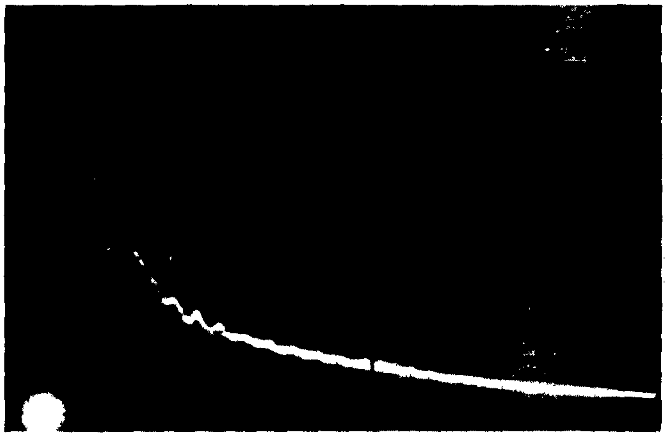
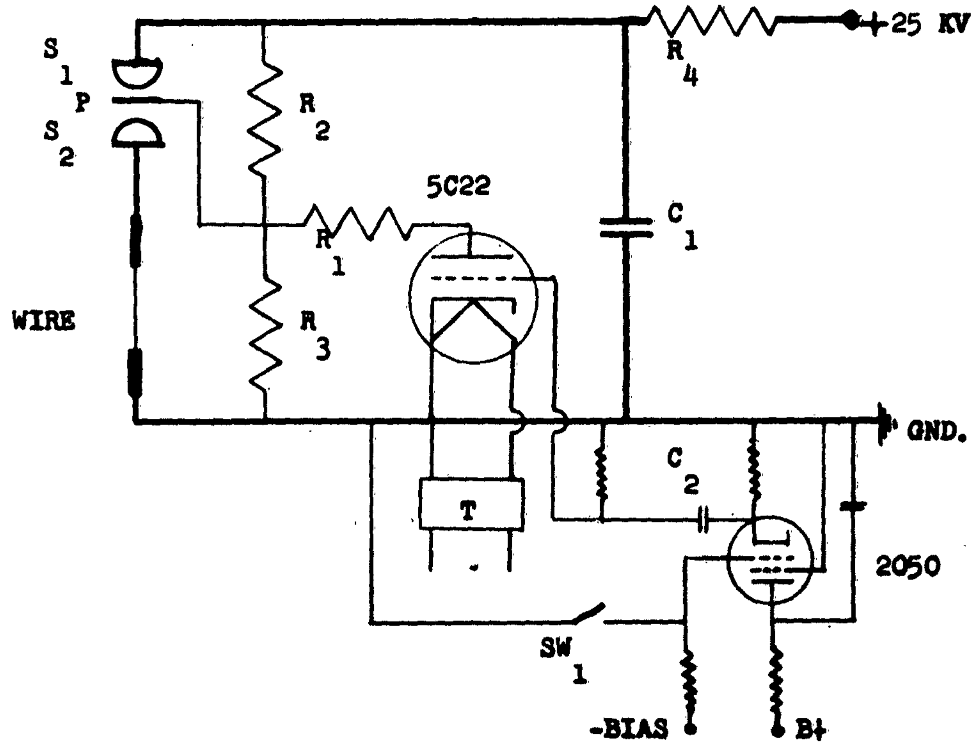


Figure 7b. Intensity (arb. units) vs. time (1/2" equals one microsecond). BH-6 Tube, 4358A°.



R_1 ....10,000 Ohms
R_2, R_3 .....100 M. Ohms
R_4 ....10 M. Ohms
C_1 ....2.5 mfd.,25 KV
C_2 ....Hi-Vo Cap

S_1, S_2 ....Brass spheres
P..............Brass plate
T..............Filament trans.

Fig. 8.

Wiring diagram of exploding wire circuit and triggering circuit.

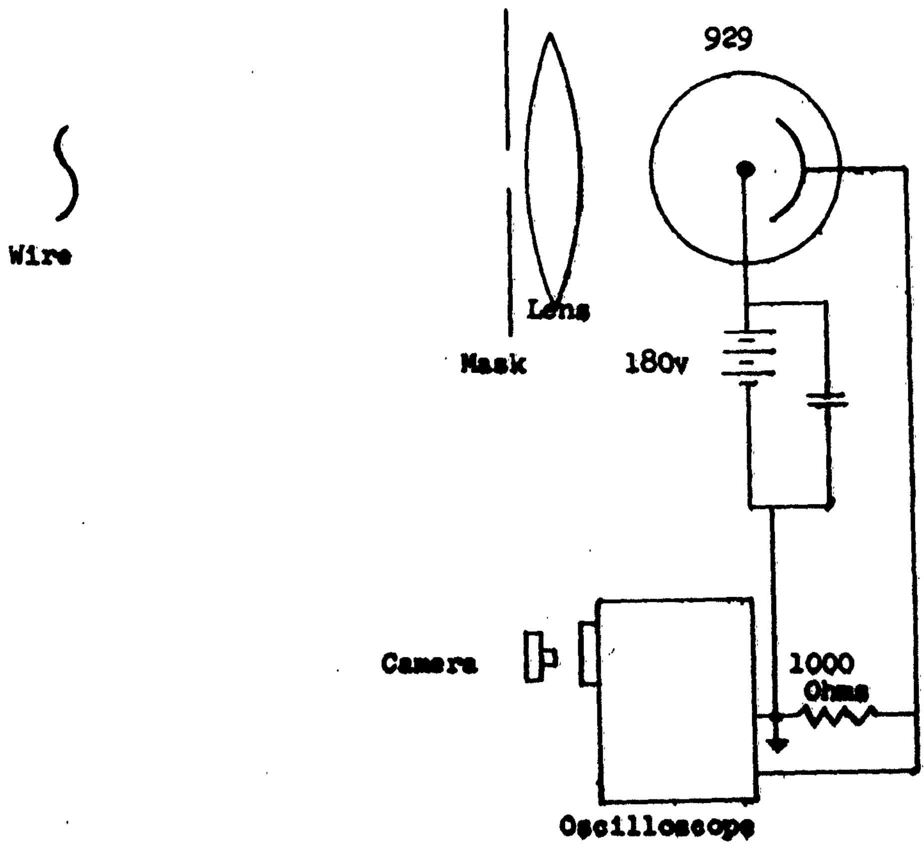
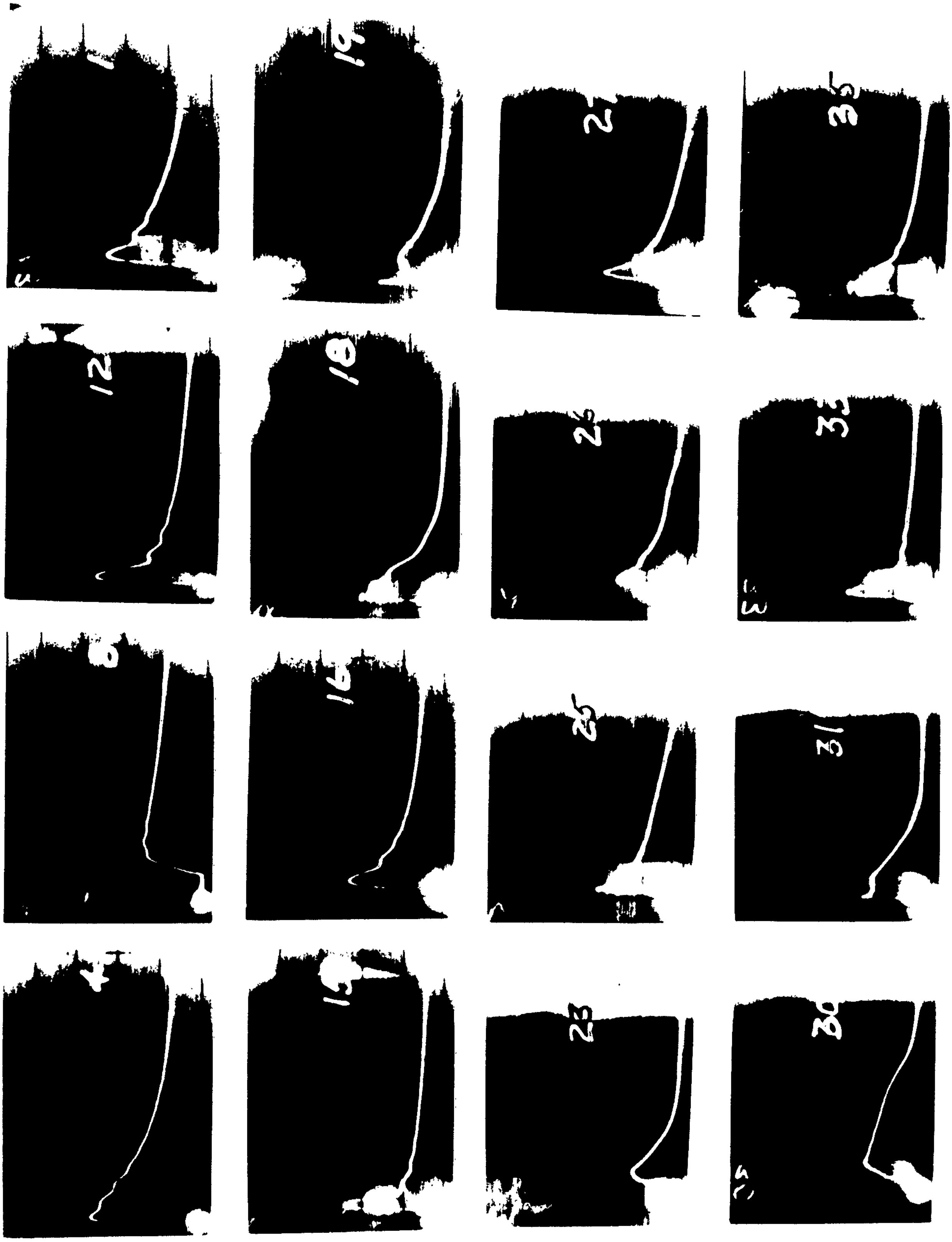


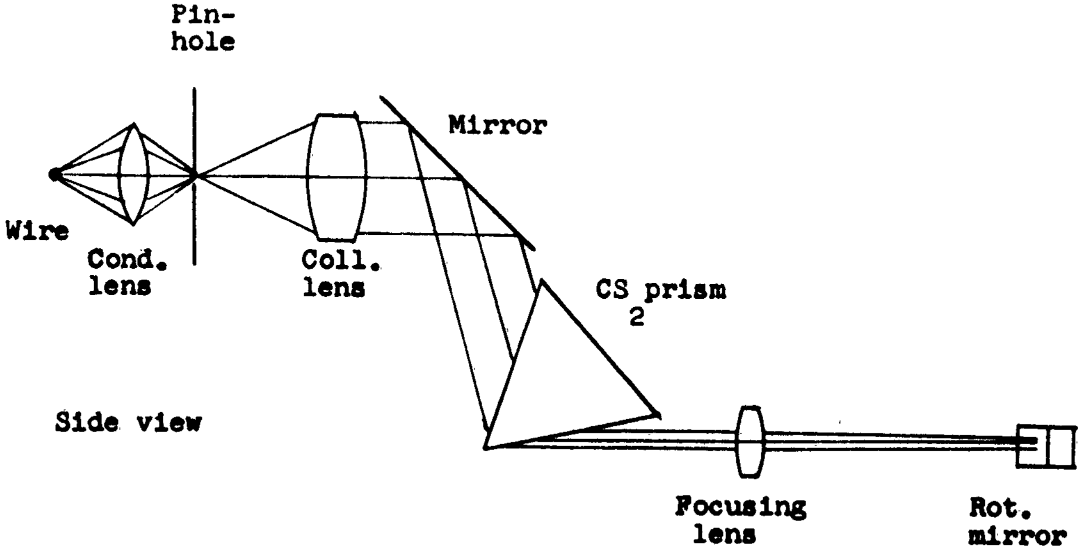
Fig. 9.

Measuring technique for white light intensity vs. duration.

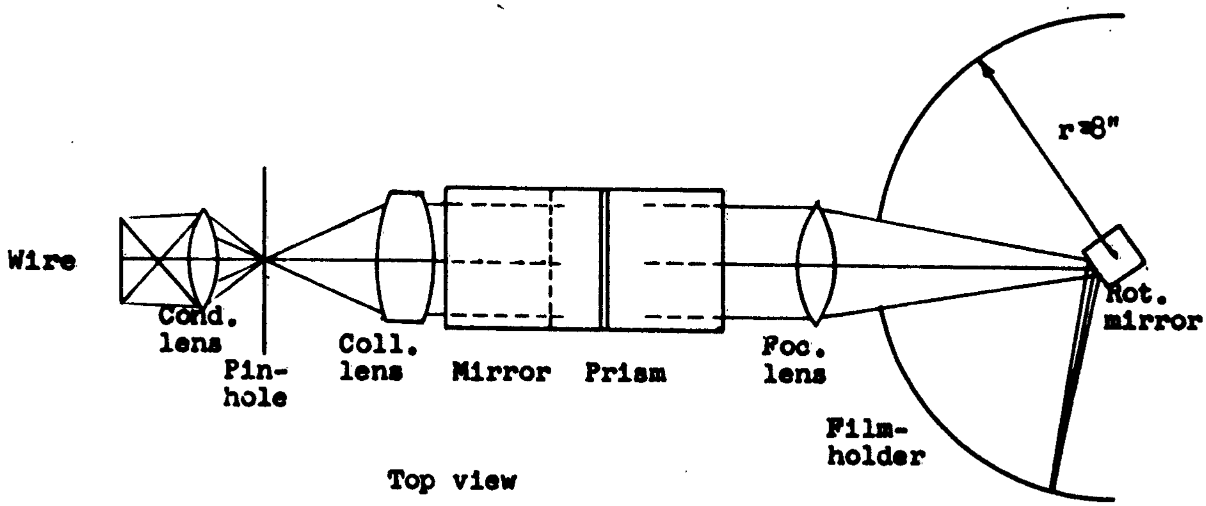
Figure 10. White light intensity vs. time

Wire	Material	Diameter	Length cm.	Modifications	Peak (arb. units)	Time to ½ peak (usec.)	Tot. time (usec.)	Peak light Candlepower
3	manganin	#40	10		822	10.0	>50	9.95×10^6
4	manganin	#40	10		790	11.0	>50	9.56
7	nichrome	#32	10		336	40.0	>50	4.43
8	nichrome	#32	10		452	36.0	>50	5.47
11	Cu-Ni	.001"	10		740	3.0	>50	8.95
12	Cu-Ni	.001"	10		780	3.9	>50	9.44
13	Cu-Ni	.001"	10	twisted yarn	714	9.2	>50	8.64
14	Steel wool	.001"	10	yarn	710	2.5	>50	8.59
15	Steel wool	.001"	10	yarn	694	2.4	>50	8.39
16	aluminum	.001"x2mm	10		668	4.3	>50	8.08
17	manganin	#40	10	in glass tube	370	9.1	23.7	4.48
18	Cu-Ni	.001	10	in glass tube	612	5.3	23.9	7.40
19	aluminum	.001"x2mm	10	in glass tube	510	6.0	23.5	6.17
20	platinum	.005"	10		710	8.2	33.4	8.59
21	steel wool	.001"	10	yarn in glass	640	4.7	26.2	7.74
22	platinum	.001"	10		728	4.5	>50	8.80
23	manganin	#40	10	in cap. tube	358	6.8	17.7	4.33
24	manganin	#40	10	in cap. tube	346	6.0	16.6	4.19
25	steel wool	.001"	10	yarn in cap.	620	5.1	24.5	7.50
26	manganin	#40	10	in plastic tube	508	6.7	23.7	6.15
27	steel wool	.001"	10	yarn in plastic	634	4.9	24	7.67
28	manganin	#40	10	back of 1/8"gls	708	12.3	>50	8.57
30	manganin	#40	10	in cap. tube	424	13.3	25.2	5.13
31	platinum	.001"	10	in cap. tube	504	6.8	15.8	6.10
33	steel wool	.001"	5	yarn	608	2.3	>50	7.36
34	manganin	#40	5		633	9.2	>50	7.67
35	aluminum	.001"x1mm	5		612	4.7	>50	7.40





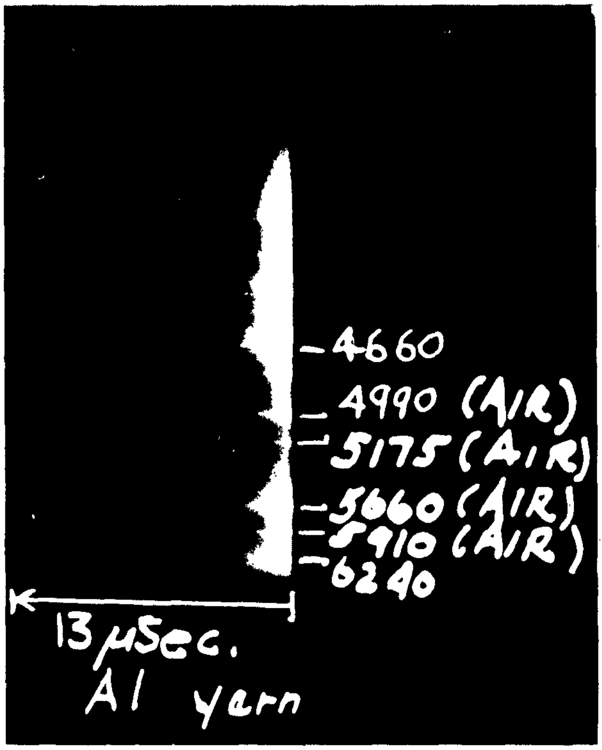
Side view



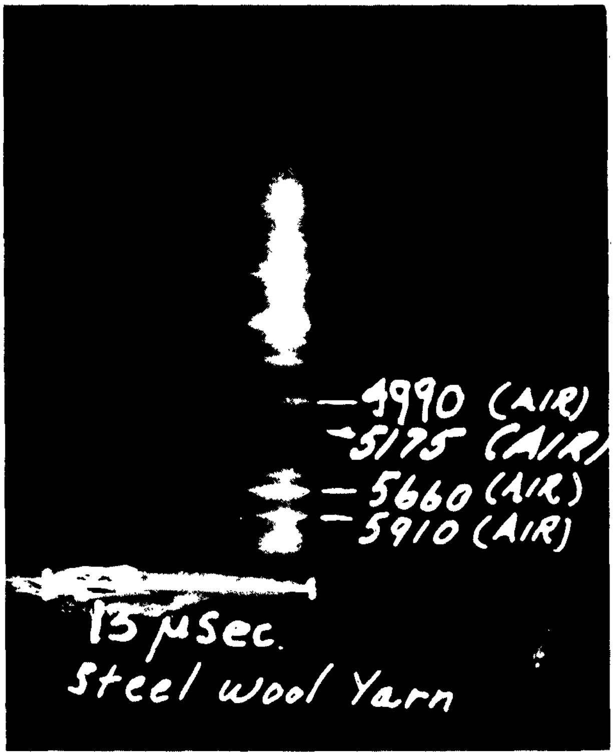
Top view

Fig. 12.

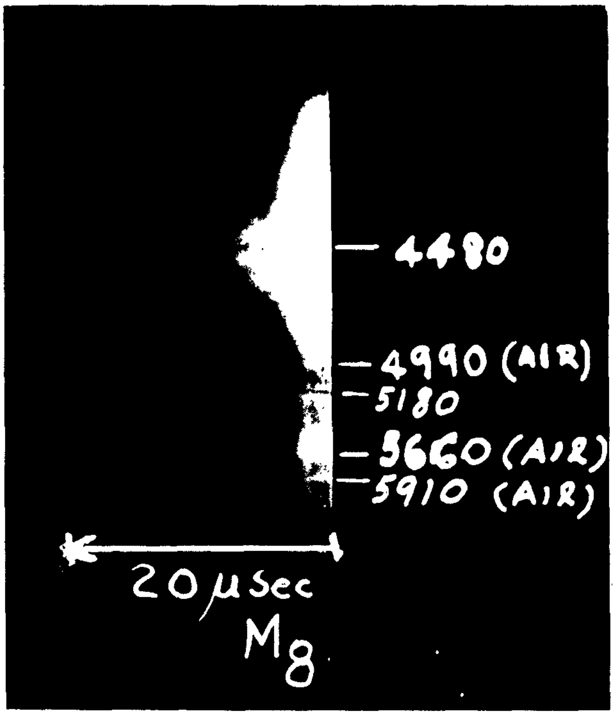
Time resolved spectrograph



13a.



13b.



13c.

Figure 13. Time resolved spectra.

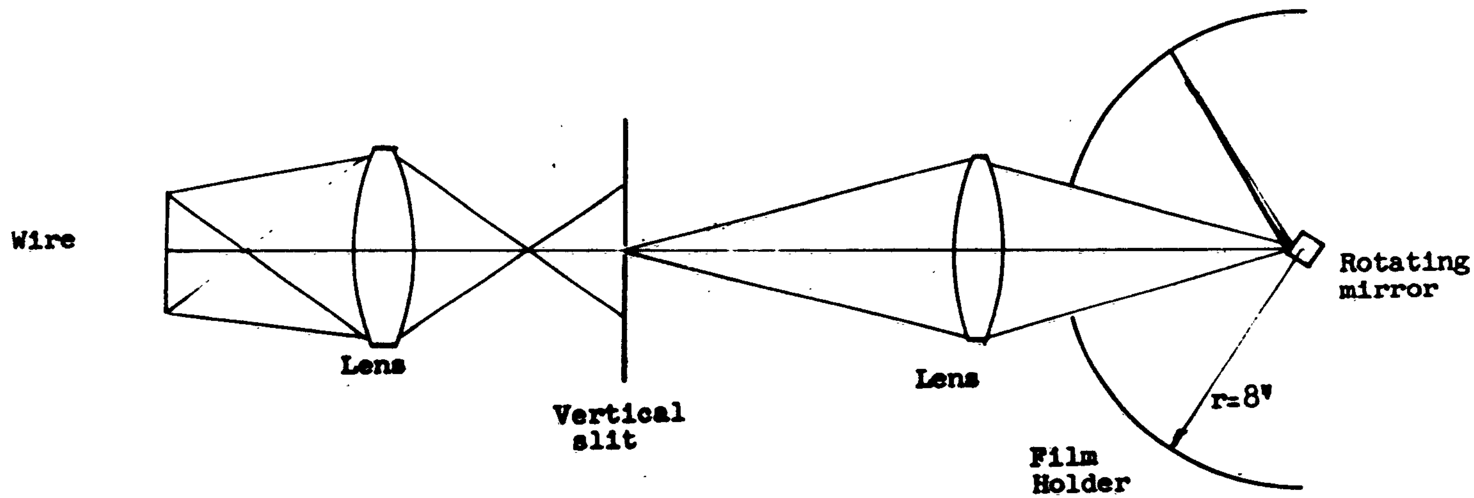
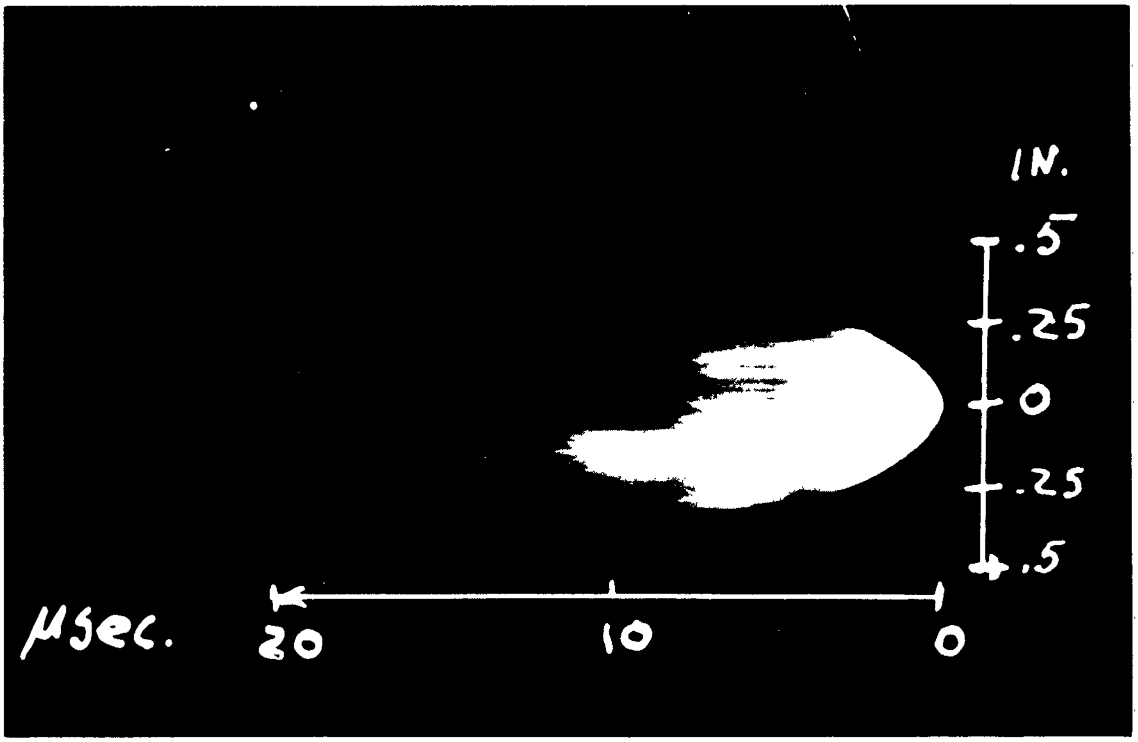
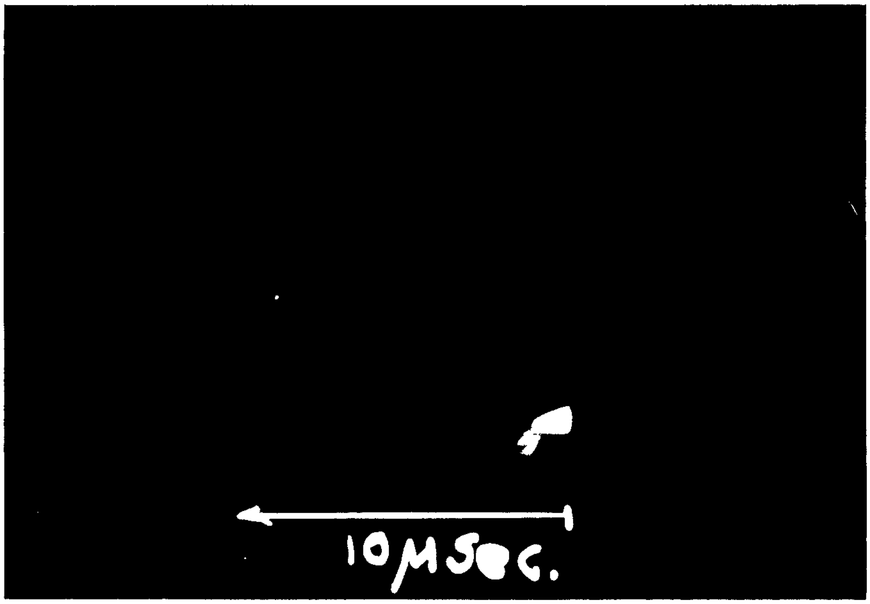


Fig. 14.

Streak camera for wire diameter as a function of time.



15a.



15b.

Figure 15. Source size vs. time.

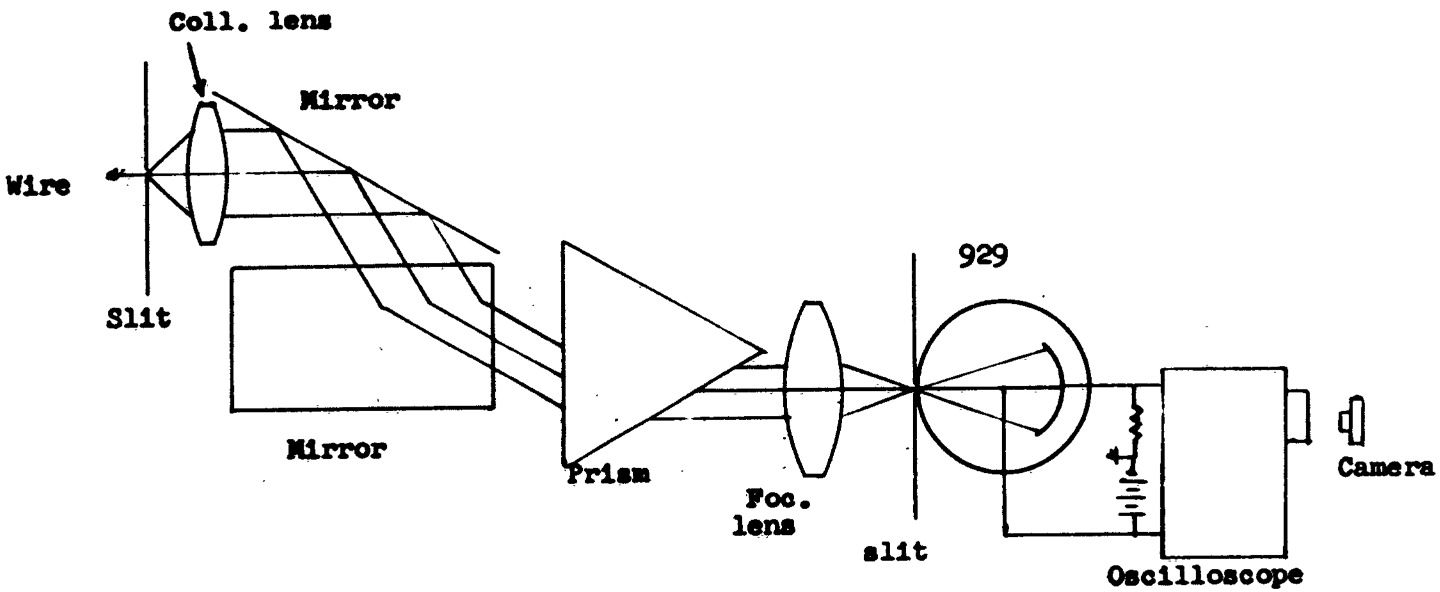
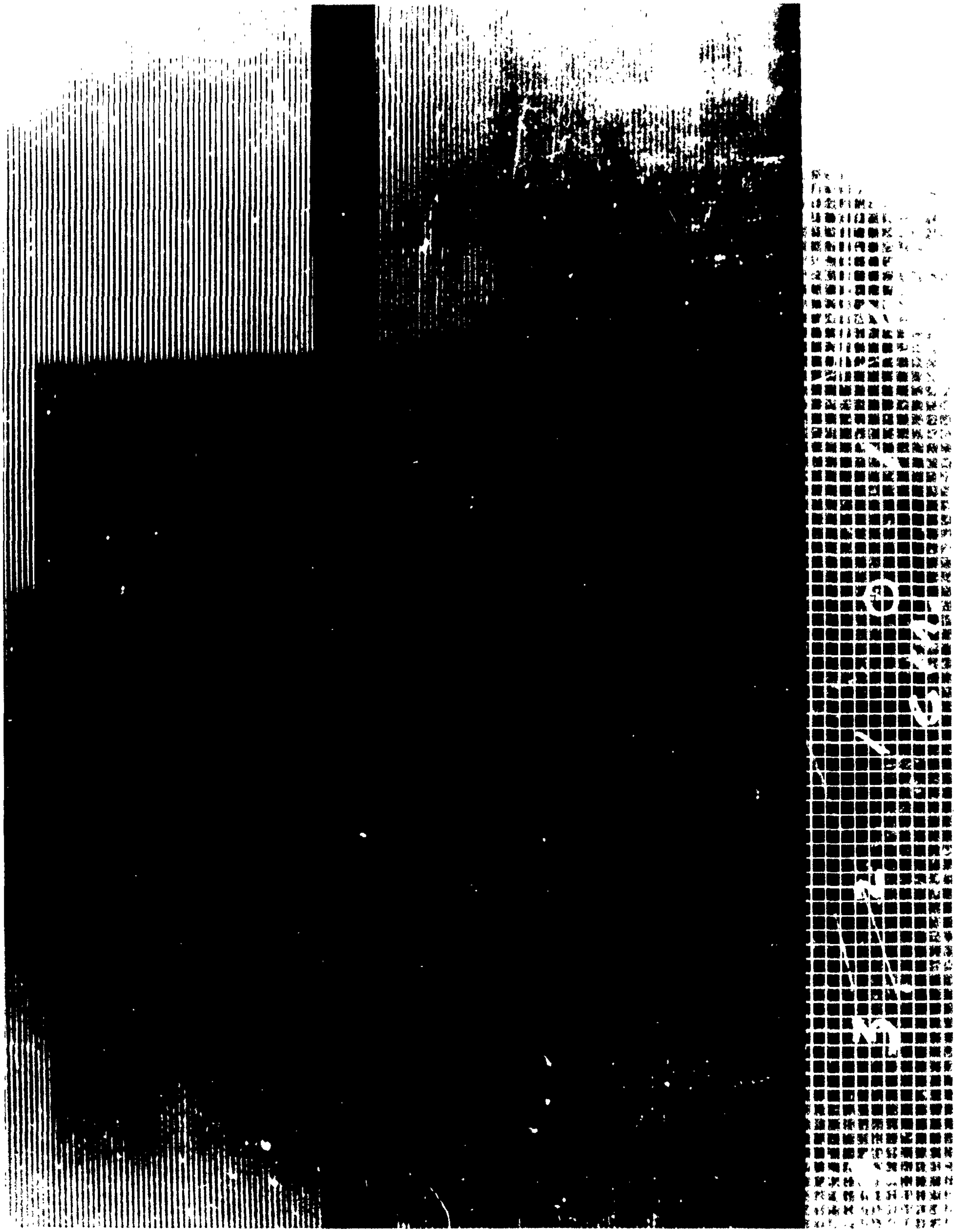


Fig. 16.

Measuring technique for monochromatic light intensity vs. duration.



APPENDIX VII

BIBLIOGRAPHY

1. J. A. Anderson and S. Smith, "General Characteristics of Electrically Exploded Wires," Astrophysical Journal 64 (1926).

2. V. E. Bergdolt and D. D. Shear, "The BH-6 Tube Light Source for Interferometry", BRL Memorandum Report No. 656.

3. F. D. Bennett, "Optimum Source Size for the Mach-Zehnder Interferometer", BRL Report No. 731.

4. F. D. Bennett, "Effect of Size and Spectral Purity of Source on Fringe Pattern of the Mach-Zehnder Interferometer", "BRL Report No. 742.

5. G. D. Kahl and F. D. Bennett, "Verification of Source Size Theory of Mach-Zehnder Interferometer", BRL Report No. 777.

6. D. B. Sleator, V. E. Bergdolt, and F. D. Bennett, "Monochromatic Light Source for Interferometry of High Speed Gas Flows", BRL Memorandum Report No. 594.

7. R. V. Heine-Geldern, "Kerr Cell Photography of High Speed Phenomena", Doctoral Dissertation, Carnegie Inst. Of Technology, June 1952.

8. Shao-Chi Lin, "Cylindrical Shock Waves Produced by Instantaneous Energy Release", Jour. Appl. Phys. 25, No. 1, 54-57, (Jan. 1954).

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